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FLUX CONTROL SYSTEM FOR METAL DETECTORS

The present application claims priority from United States
10 Provisional Patent Application No. 60/446,747, filed on February
12, 2003.

BACKGROUND OF THE INVENTION

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1. Field of Invention

This invention pertains generally to the field of metal
detection, and more particularly to controlling the shape of the
20 magnetic field used in such a device.

2. Description of Prior Art

Metal detectors are used in the food processing industry, for
25 example, to detect contaminants within a product. The unwanted
material may include very small metallic particles having
differing compositions. The typical metal detector is housed in
an enclosure containing a longitudinal aperture through which the
product under test is transported, usually by means of a conveyor
30 belt. The metal detector includes a transducer or oscillator that
radiates a magnetic field by means of some arrangement of coils.

In particular, the typical metal detector includes a search
head which contains both radiating and receiving coils, the search
35 head being formed to include the aperture or passageway through
which the product travels. The oscillator coil is a wire loop
residing within the search head. The oscillator coil surrounds
the aperture and receives stimulus from an oscillator circuit. The
search head also includes an input coil connected so as to produce

5   a zero or balanced input signal when no metal is present. A
disturbance in the radiated magnetic field is sensed by the input
coil and processed in some manner in order to discern the presence
of metal within the product passing through the detector
enclosure.   A nonzero input signal as measured across the input
10   coil is due to either mechanical imbalances in the construction of
the search head, inherent electrical changes in the circuitry
(such as frequency drift), metal being introduced into the
aperture, or the effect of the product itself.

15   Modern digital signal processing techniques resolve the input
signal into two signal components, one component being resistive
and the other signal component being reactive.   The "product
effect" caused by the product passing through the aperture is due
primarily to electrical conduction via salt water within the
20   product, the electrical conduction causing large magnitude
resistive signals and relatively smaller reactive signals.

      When a metal detector is used in the food processing
industry, the detector is typically placed in a location which is
25   a part of the existing food processing line. Due to constraints in
processing the food items, there is often little discretion in
choosing where the detector will reside. The detector is often
placed in close proximity to other metal objects, such as
conduits, casings, cabinets and other metal fixtures.   Equipment,
30   such as pumps and conveyors can vibrate or move with respect to
the fixed position of the metal detector. The magnitude of the
effect of such equipment on the metal detector is dependent on the
size of the detector aperture, the operating frequency, the
magnitude of the operating current, the size and location of the
35   surrounding equipment (including other metal detectors that are
operating at the same frequency),the type of material being tested

5   and the magnitude and frequency of any vibration or movement. In many situations, the magnitude of external interference is sufficient to cause the metal detector to falsely indicate the presence of metal in the product under test.

10   In order to provide some measure of electromagnetic shielding, the detector enclosure is usually constructed of metal, but this typically requires that the coils be separated some distance from the walls of the metal enclosure in order to minimize the effects caused by enclosure vibration, heating and
15   aging. Vibration caused by relative movement of the enclosure with respect to the coils causes a disturbance in the radiated electromagnetic field that may easily be mistaken as the sensing of contaminant metal. The magnitude of a vibration related disturbance increases as the distance between the coils and the
20   metallic enclosure walls is reduced. In general, any metal residing within or near the detection aperture is likely to be sensed as a contaminant particle or object even when the metal is part of the detector structure or enclosure. A method of canceling or accounting for such residual or nearby metal is a major
25   challenge affecting the design of metal detection equipment.

      Within the metal detector aperture is an area which may be properly termed as the detection zone. The detection zone is a region in which the product is subjected to the peak magnetic
30   radiation of the oscillator coil and any disturbance in the magnetic field is assumed to be attributable to the presence of unwanted metal contaminants. Unfortunately, since the magnetic field extends beyond the detection zone, there is an additional region in which no metal should reside, typically referred to as
35   the "metal free zone". In real world metal detector installations, the desired metal free zone is often several times

larger than the volume of the detector aperture. Achieving such a substantial metal free zone often creates problems in a food processing or other production environment.

One method of reducing the volume of the metal free zone is to reduce the physical boundaries or extent of the magnetic field produced by the oscillator coil. An example of a device which employs this technique is disclosed in United States Patent No. 5,572,121, entitled METAL DETECTOR INCLUDING A METAL SCREENING FOR PRODUCING A SECONDARY MAGNETIC FIELD TO REDUCE THE METAL FREE ZONE, issued on November 5, 1996 to Beswick. The Beswick device places a metal screen or grid adjacent to the oscillator coil. The metal screen induces a secondary magnetic field which is in opposition to the primary magnetic field, thereby constricting the size of the primary magnetic field and the volume of the metal free zone. The Beswick device functions only when the screens or plates form a continuous shield around the inside of the aperture, that is, when the starting and ending edges of the screen are electrically connected.

Despite past improvements, a need exists to further address the problems inherent in state of the art metal detection equipment, including the effects due to vibration and the problems caused by an enlarged metal free zone in the region adjacent to the aperture.

SUMMARY OF THE INVENTION

The current invention relates to improvements in the function of a metal detector. In particular, the present invention increases the immunity of a metal detector to vibration, as well

5   as to the movement of metal in regions adjacent to the search head
    aperture, by monitoring the ratio of the signal amplitudes induced
    in the windings of the input coils.

    The movement of metal in the metal free zone has the same
10 characteristic input signal traits as metal moving due to
    vibration of the metal case which serves as the detector
    enclosure. In either case they are metal objects moving within
    the metal free zone. By recognizing and removing signals
    associated with vibration, the present invention permits the use
15 of greater sensitivity in the processing of signals. The volume
    of the required metal free zone is reduced because the ability to
    remove signals associated with case vibration also permits the
    removal of the similarly characterized signals that are associated
    with the movement of metal adjacent to the aperture.
20
    The present invention also includes a technique for improving
    the magnetic flux associated with the use of relatively large
    search heads. When using a large search head, the inductance of
    the oscillator coil is large due to the greater size. The
25 inductive reactance X_L of the oscillator coil is therefore larger,
    being equal to $2\pi fL$, where f is the frequency of operation and L
    is the inductance of the coil. According to Ohm's law, for a given
    excitation voltage applied to the oscillator coil, the larger
    reactance will cause a relatively smaller current to flow through
30 the coil. Since magnetic flux is directly related to the magnitude
    of the current, a large search head will produce a smaller
    magnetic flux density in the center of the aperture. One
    embodiment of the present invention uses two oscillator coils
    connected in a parallel relationship to generate up to twice the

5   magnetic flux density for a given excitation voltage whenever a
relatively larger search head is required.

In the case of a small search head, the inductance is
necessarily smaller due to the smaller size. In this
10   circumstance, a given voltage will result in a relatively high
current. The current is typically so high, in fact, that the
voltage must be reduced to prevent the coil current from exceeding
a value that would cause signal distortion, thereby raising the
background noise level and hence reducing detector performance.
15   An alternate embodiment of the present invention uses two
oscillator coils interconnected in a series relationship so as to
produce approximately twice the magnetic flux density for a given
excitation voltage whenever a relatively smaller search head is
required.
20

The present invention includes an input coil formed as two
coils that are coaxial with the oscillator coil. The resultant
three-coil arrangement is connected such that a zero net input
voltage is produced under quiescent conditions. The present
25   invention also includes a technique for improving the magnetic
flux by the addition of a flux concentrator in the form of at
least one ferrite slab or sheet positioned adjacent to the coils
increasing the inductance of the oscillator coil, thereby
increasing the magnetic flux for a given coil current.
30

The oscillator coil inductance increase produced by the flux
concentrator is not needed in some regions of the search head,
most specifically in the corners of the aperture. The
contribution derived from the oscillator coil corners to the flux
35   density in the center of the aperture, where the product under
test resides, is small. By reducing the inductance in the corners

5   where it is not needed, the net inductance of the coil remains the
    same. This maximizes magnetic flux where it is most useful, that
    is, displaced from the aperture corners. Since the net inductance
    is substantially the same, substantially the same oscillator
    current will flow. If this was not the case then the effect of
10 adding the flux concentrators would be reduced because the current
    magnitude would be smaller.

    All of the techniques of the present invention together
    produce cumulative improvements in the resultant metal detecting
15 apparatus. For example, the use of a series coil arrangement in
    conjunction with a relatively smaller search head, when combined
    with a flux concentrator, can reduce the size of the smallest
    detectable contaminant. Typically this means that a detector
    previously capable of detecting a particle having a diameter of
20 0.8 mm will be able to detect a particle having a diameter of 0.6
    mm. The ability to ignore the effects of case vibration permits
    greater sensitivity. This further reduces the diameter of
    detectable contaminants from 0.8 mm to approximately 0.4 mm.

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    BRIEF DESCRIPTION OF THE DRAWINGS
    FIG. 1 is a perspective view of a metal detector constructed
30 according to the principles of the present invention;

    FIG. 2 is a graph depicting the relationship between components of
    the input signal produced by the metal detector of Figure 1;

35 FIG. 3 is a graph depicting the relationship between induced
    voltages in the input coils of the metal detector of Figure 1;

5   FIG. 4 is a simplified perspective view of the oscillator coils
utilized in a first embodiment of the present invention;

Figure 5 is a simplified perspective view of the oscillator coils
utilized in a second embodiment of the present invention; and

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Figure 6 is a simplified perspective view of the aperture and flux
concentrator utilized in the metal detector of Figure 1.

15 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG.1, a metal detector constructed according to
the principles of the present invention is shown generally at 1.
The metal detector includes a metal or conductive cabinet. The
20 metal detector 1 includes a metal or conductive cabinet 2,
typically stainless steel or aluminum that is supported by shock
absorbing feet 3 and 4. The cabinet is formed to include a
generally rectangular first sidewall 5. The sidewall 5 includes an
opening or first aperture 6 which permits access to the interior
25 volume of cavity 7. The cavity 7 is bounded by a coaxially
aligned second aperture 9, such that an article (not shown) may
enter the cavity 7 through first aperture 6 and exit cavity 7
through the second aperture 9. The article may enter the cavity 7
via a conveyor, which may be a belt or chain as well as a gravity
30 feed mechanism or a pump forwarding the article through a conduit.
In an alternate embodiment (not shown) the aperture may have a
circular shape, and the entire cabinet may also be generally
circular or toroidal in configuration. Further, the aperture may
be of the so-called "single sider" type commonly used, for
35 example, in the carpet industry, where the metal detector has a

5   single sensitive side or face in which all of the coils are
     embedded.

        An oscillator coil 10 resides within cabinet 2. The
     oscillator coil 10 surrounds and substantially bifurcates the
10   cavity 7. As seen in FIG. 10, the oscillator coil 10 is excited or
     driven by the oscillator or transmitter 11, which is housed within
     the region 12 of cabinet 2. Symmetrically spaced on opposite sides
     of oscillator coil 10 is a front input coil 13 and a rear input
     coil 14. Coils 13 and 14 are connected to each other in series
15   opposition.

        The oscillator 11 produces a low frequency magnetic signal
     typically in the range of thirty kilohertz to two megahertz. The
     oscillator 11 is coupled to the oscillator coil 10 through leads
20   20 and 21. The oscillator coil 10 acts as an antenna, radiating
     the signal produced by oscillator 11 and producing a magnetic
     field within and somewhat beyond cavity 7. The input coils 13 and
     14 reside within the magnetic field produced by oscillator coil
     10.
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        In the absence of metal, and due to their series opposition
     interconnection, the signal induced in the front coil 13 from
     oscillator coil 10 is of the same magnitude but opposite polarity
     as the signal induced in the rear coil 14, thereby producing a
30   resultant signal of zero volts. When metal is present, or due to
     small irregularities in the position of coils 13 and 14, or the
     location of the case 2, or the presence of contaminant metal, it
     distorts the symmetry of the magnetic field produced by oscillator
     coil 10, thereby causing signals of different magnitude to appear
35   on coils 13 and 14. This imbalance produces a signal having a
     magnitude that is greater than zero volts.

5   The strength of the signal produced by the input coils 13 and
       14 is a function of the size, shape and composition of the coils
       13 and 14, the absolute strength of the magnetic field produced by
       oscillator coil 10, the size of the metal object (not shown), the
10   composition of the metal object, the distance between the metal
       object and the input coils 13 and 14, and the distance of the
       metal object from the oscillator coil 10. The closer the metal
       object is to the oscillator coil 10, the greater will be the
       distortion of the magnetic field transmitted by oscillator coil
15   10. A relatively greater field distortion on one input coil
       produces a relatively greater unbalance in the signals induced in
       input coils 13 and 14. Similarly, the closer the metal object is
       to either receiver coil 13 or 14, the greater the imbalance in the
       amount of signal induced in either coil. Thus, a greater distance
20   between the metal object and any of the coils reduces the
       magnitude of the unbalanced signal. Typically, the input coils 13
       and 14 are arranged and spaced in such a manner so as to maximize
       the magnitude of the unbalanced signal when the metal object is
       passed through the center of the cavity 7.
25
           The oscillator 11 operates at a discrete, continuous wave
       radio frequency typically in the range of 0.030 to 2.00 megahertz.
       The magnetic field emitted by oscillator coil 10 is coupled to the
       adjacent input coils 13 and 14 by magnetic induction creating
30   signals in both. Since the coils 13 and 14 are wired in series
       opposition, there is no resultant output signal when metal (or
       other electromagnetic field distorting medium) is absent from the
       vicinity of the emitted magnetic field.

35   Referring also to Figure 3, when a moving metal article is
       brought into proximity with the radiated magnetic field of

5   oscillator coil 10, the magnetic field effectively undergoes
     amplitude and phase modulation, that is, the magnetic field
     density varies with respect to time. The modulation frequency is
     typically in the range of 0.10 to 100 hertz. The actual frequency
     is dependent on the speed of the metal (or product) passing
10   through the aperture as well as the coil separation.

     The signal 8 received by coil 13, for example, will have an
     amplitude and an amplitude modulation frequency that is dependent
     on the metal (or product being tested) characteristics as well as
15   the velocity of the metal as it passes through the detector cavity
     7.   The waveform 8 depicts the change in voltage across the input
     coil 13 when metal passes by the coil. In fact the change in
     voltage is of the order of a few tens of nanovolts (for a small
     contaminant) superimposed on a standing voltage of up to ten
20   volts. The standing voltage is the same on each coil 13 and 14.
     By wiring the coils 13 and 14 in an anti-phase relationship, the
     relatively large standing voltage is removed.   The axis 16
     represents the magnitude or amplitude of the signal 8 in units
     such as volts, while axis 15 represents the distance traveled or
25   horizontal displacement of the metal contaminant.

     The point 17 of signal 8 represents a point of time when no
     metal or product is in the detector cavity 7. The signal 8 is
     representative of the signal appearing on one input coil 13, which
30   remains the same regardless of the signal on the other input coil
     14. As metal enters the location in the detector cavity 7 and
     approaches the first input coil 13, the magnitude of signal 8
     changes and has an amplitude modulation envelope peak 18 which
     corresponds to the metal object passing between oscillator coil
35   and coil 13. This is followed by a second amplitude modulation
     envelope peak 19 attributable to signal 24 which corresponds to

5   the metal object passing between oscillator coil and coil 14. The
    time difference between the envelope peaks 18 and 19 along axis 15
    indicates the absolute frequency of the amplitude modulation,
    which is dependent on the parameters mentioned previously. The
    closer the coils 13 and 14 are to the center of the cavity 7, and
10 hence to the oscillator coil 10 which resides at the center of the
    cavity 7, the higher the frequency of the amplitude modulation due
    to the shorter period of time needed for passage of the object
    over the coils 13 and 14.

15   If metal resides at the aperture center 20, the magnitude of
    the voltage induced in each input coil will be substantially
    equal, corresponding to the magnitude of, for example, point 21.
    Similarly, if the metal object is nearer to coil 13, the magnitude
    22 of the voltage induced in coil 13 is greater than the magnitude
20 23 of the voltage induced in coil 14 at the same moment. In other
    words, the magnitude of the voltage induced in the nearer coil is
    measurably greater than the voltage induced in the more distant
    coil. Only metal residing in the center 20 of the cavity 7 will
    produce a ratio of voltages in coils 13 and 14 that is
25 approximately 1:1.

    By measuring the ratio of the voltages 8 and 24 induced in
    each coil, respectively, at the same instant, the position of the
    metal within the cavity can be calculated. A recognition that the
30 signal produced on the input coils 13, 14 is the result of metal
    located within the cavity permits signals not corresponding to an
    "in cavity" location to be excluded as either the result of
    vibration or attributable to metal external to the metal detector
    1. By monitoring the position of the each contaminant using the
35 ratio method just described, the position of a second contaminant

5   can be determined and its effect on the signal attributable to the
     first contaminant can be recognized.

          Referring also to Figure 2, the composite signal produced by
     the combination of signals 8 and 24 can be divided into two
10   separate components by appropriate signal processing. The
     reactive component includes signals 26 that are due primarily to
     case vibration and the movement of metal that is external to the
     cavity 7, as well as signals 27 attributable to large nonferrous
     electrically conducting items and signals 28 caused by the
15   presence of small ferrous contaminants. Sensitivity to the
     detection of the small iron particles indicated by signal 28 is
     greatly increased if the vibration related signal 27 is
     eliminated, as is made possible by the technique of monitoring the
     ratios of the input coil signals 8 and 24.
20

          Referring also to Figure 4, a first improved oscillator coil
     arrangement can be understood. The oscillator 11 is capable of
     delivering a current of approximately 11 amperes root mean square
     (11A RMS). When the oscillator coil 10 surrounds an aperture
25   having dimensions of, for example, 350 mm by 150 mm, the coil
     inductance limits the actual coil current to 7.5A RMS at 300 kHz
     because the peak to peak voltage from the oscillator is also
     limited, in this case to 40v. An aperture size of 600 mm by 200
     mm will create a current of only 3A, which represents a
30   significant reduction in radiated magnetic flux from that which is
     theoretically available from the oscillator 10.

          If two oscillator coils were to be placed side by side at the
     center of the cavity 7, no net gain in magnetic flux would be
35   achieved because of the cross coupling of the magnetic fields.
     Therefore, the present invention utilizes two oscillator coils 29

5   and 30 which are spaced apart a sufficient distance 40 to permit
    the generation of largely separate magnetic fields. The input
    coils 13 and 14 reside outside of the volume defined by the
    oscillator coils 29 and 30, the input coils being connected to
    input signal processing circuitry 42. The optimum spacing between
10 coils 29 and 30 is approximately half the distance 41 between the
    input coils 13 and 14. The two oscillator coils 29 and 30 are
    wound in parallel to create a twin coil 31 which is fed by
    oscillator leads 20 and 21. The coils 29 and 30 may be arranged
    so that their fields are either additive or in phase opposition.
15 The total current drawn by the combined twin coil 31 is
    substantially greater than a single coil having the same
    dimensions. For an aperture size of 600 mm by 200 mm, the current
    increases from approximately 3A for a single coil to approximately
    5A for the twin coil 31. The radiated magnetic flux is directly
20 proportional to the current drain, the increased flux thereby
    causing the absolute magnitude of the peak signals 18 and 19 to
    increase, thereby simplifying their detection and measurement.
    Further, because each input coil 13, 14 is physically closer to
    its adjacent oscillator coil 29 and 30, respectively, the signal
25 to noise ratio is further improved. In theory, the overall net
    gain achieved with the twin coil 31 is approximately 100% greater
    than the single oscillator coil configuration. This gain
    improvement translates into detection of metal particles that are
    approximately 25% smaller. Table I compares the expected
30 performance of the present arrangement with the previous single
    oscillator coil method for an actual metal detector.

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Table I

Number of Oscillator Coil Windings	Peak Detector Signal Readings For The Given Contaminant Size and Type		
	1 mm Fe	1.5 mm NFe	2.0 mm SS
One	360	280	385
Two	500	480	560

10

Table I shows that the peak reading produced by the twin oscillator coil arrangement produces significantly higher peak detector readings. In particular, the improvement afforded by the dual coil system of the present invention shows an improvement

15 factor of 1.38 for Fe (Iron), 1.71 for NFe (Nickel and Iron) and 1.45 for SS (Stainless Steel).

Referring also to Figure 5, a second improved oscillator coil configuration can be understood. A relatively smaller oscillator

20 coil such as would be associated with a relatively smaller aperture will have a relatively smaller value of inductance. The small inductance value necessarily means that the oscillator coil will draw a relatively greater current. Since the oscillator 11 cannot deliver more than 11A RMS, the driving voltage delivered by

25 the oscillator 11 to the oscillator coil 10 must be limited in order to prevent excessive current demand. A typical standard sized oscillator coil may have a potential difference of 40 volts

5   peak to peak (40Vp-p), whereas a smaller dimensioned oscillator
     coil may permit an oscillator voltage of only 10Vp-p.

     The improved oscillator coil assembly 32 is constructed to
     include two separate oscillator coils 33 and 34, which are seen to
10   be wound in series by the arrangement of the input leads 20 and
     21. The coils 33 and 34 may be arranged so that their fields are
     either additive or in phase opposition. The typical theoretical
     improvement in the radiated magnetic flux is approximately 3:1,
     which increases to approximately 4:1 if the coils 33 and 34 are
15   placed relatively close to the center of the cavity 7.
     Alternatively, for a given voltage, the current could be reduced
     by a factor of 4:1 if the original level of magnetic flux is to be
     maintained. However, since the current drain has been reduced by a
     factor of four, the voltage produced by oscillator 11 can be
20   increase by a factor of four without exceeding the maximum
     permissible current drain, thereby permitting an increase of 4:1
     in the radiated magnetic flux.
     In practice, the actual improvement in magnetic flux is often
     limited to about 2.5:1 due to the proximity of the case 2.
25

     The same 2.5:1 flux improvement ratio can also be achieved by
     placing each of the two oscillator coils 33 and 34 relatively
     closer to their adjacent input coil 13 and 14, respectively. This
     increased spacing between the oscillator coils 33 and 34 cause
30   them to act substantially independently and behave as two
     inductors in a series circuit. The net inductance increase is
     therefore 2:1 which corresponds to a doubling of the radiated
     magnetic flux when the voltage of oscillator 11 is doubled.
     However, a metal object passing close to input coil 13, for
35   example and its associated oscillator coil 33 will cause a minute
     change in the oscillator voltage across coil 33. The change in

5   oscillator voltage causes a corresponding change in the magnitude
     of the current drawn from the oscillator 11, the change being
     perceived or forwarded to the other oscillator coil 34 since the
     two coils 33 and 34 are wound in series. The result of the
     voltage and current change is to produce an additive signal which
10   creates a potential flux improvement of approximately 2.5:1. A
     radiated flux improvement of 2.5:1 corresponds to a decrease in
     size of the minimum detectable contaminant of approximately 35%.

     Once the flux density of the radiated magnetic field has been
15   selected based on the dimensions of apertures 6 and 9, the shape
     of the resultant magnetic field may be controlled. Referring also
     to Figure 6, the cavity 7 is seen to be surrounded by oscillator
     coil 10 and input coils 13 and 14. A first method of controlling
     the shape of the radiated field is to place conductive flux plates
20   36 and 35 adjacent to and completely encircling the apertures 6
     and 9, respectively. The flux plates 35 and 36 are formed of a
     conductive material such as metal and are placed in regions of the
     cavity 7 in which the magnetic field is to be excluded. The
     magnetic field is not actually absorbed by the flux plates 35 and
25   36, but rather serve to repel the magnetic field, concentrating
     the field toward the central interior regions of the cavity 7 and
     thereby increasing the flux density in the region of the cavity 7
     that is most likely to be occupied by the product under test.

30   A second method of shaping the radiated electromagnetic field
     is by means of a flux concentrator 37, which is formed of a
     ferrite slab, sheet or block. The flux concentrator 37 is placed
     adjacent to, but insulated from, the coils 10, 13, and 14,
     preferably extending as a continuous mass that overlies a portion
35   of each coil. The effect of the flux concentrator 37 is to
     increase the magnetic flux in the region near the concentrator 37.

5   Therefore, the concentrator 37 is typically placed so as to
overlie a central region of the cavity 7 so that magnetic flux
will be increased near the central region of cavity 7.   Since the
radiated magnetic field has a finite total flux, the increase in
the flux density near the concentrator 37 necessarily reduces the
10   flux density in regions displaced from the flux concentrator 37.

The flux concentrator 37 has the effect of increasing the
inductance of the oscillator coil 10.   Since the inductance may be
defined as the magnetic flux produced per ampere of current, the
15   magnetic flux produced by a given current necessarily increases as
the inductance is increased.   The increased magnetic flux in the
region surrounding the coils 10, 13 and 14 translates into greater
signal amplitudes produced by input coils 13 and 14 for a given
field disturbance, such as would be caused by the passage of a
20   metallic object through the cavity 7.   The flux concentrator 37
must be mounted within cabinet 2 in a secure manner that will
preclude any vibration of concentrator 38.   Further, the ferrite
material cannot have a permeability value that is so high as to
significantly detune the oscillator coil frequency with changes in
25   temperature.   In order for the net detuning effect to be
acceptably small, the improvement in signal gain due to the
concentrator 37 cannot exceed a ratio of approximately 2:1, which
corresponds to a size reduction of the smallest detectable
contaminant by approximately 25%.
30

The foregoing improvements embodied in the present invention
are by way of example only.   Those skilled in the metal detecting
field will appreciate that the foregoing features may be modified
as appropriate for various specific applications without departing
35   from the scope of the claims.

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Abstract

10   A metal detector (1) used for identifying contaminants in products. The detector (1) includes an oscillator coil (10) that may be formed as two series wound coils (34, 35) having relatively smaller dimensions or as two parallel wound coils (29, 30) having relatively larger dimensions. A pair of input coils (13, 14) is

15   located adjacent to the oscillator coil (10). A first signal (8) is generated by the first input coil (13) in response to the presence of a metallic object, while a second signal (24) is generated by the second input coil (14) in response to the presence of a metallic object. By measuring the ratio of the

20   first signal (8) to the second signal (24) the physical location of a metal object within the metal detector cavity (7) can be determined.

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Claims

I claim:

30   1. A metal detector, comprising:

       (a)   a radio frequency oscillator;

       (b)   an oscillator coil, the coil being electrically

35   interconnected to the oscillator so as to emit a magnetic field in a region surrounding the oscillator coil;

5   (c)   a first input coil residing within the magnetic field, the first input coil generating a first signal in response to a disturbance of the magnetic field;

       (d)   a second input coil residing within the magnetic field,
10   the second input coil generating a second signal in response to a disturbance of the magnetic field; and

       (e)   a signal processor, the signal processor measuring a ratio of the first signal and the second signal so as to determine
15   a physical location of an item causing the disturbance of the magnetic field.

       2.   The metal detector according to claim 1, wherein the signal processor records a first peak attributable to the first signal
20   and the signal processor records a second peak attributable to the second signal, the signal processor determining a direction of travel of the item causing the disturbance of the magnetic field.

       3.   The apparatus according to claim 1, wherein the metal detector
25   further comprises:
       (a)   a case, the case housing the oscillator, the oscillator coil, the first and second input coils, and the signal processor;

       (b)   a cavity, the cavity residing within the case, the
30   cavity being dimensioned to house a product while being examined for metal contaminants;

       (c) a first aperture formed within the case and permitting the product to enter the cavity;
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       (d) a second cavity, the second cavity being formed within the case and permitting the product to exit the cavity; and

(e) a conveyor, the conveyor transporting the product through the cavity

4. An apparatus according to claim 1, wherein the signal processor associates a disturbance of the magnetic field with a metallic item when the item is determined to reside within the cavity.

5. An apparatus according to claim 1, wherein the signal processor excludes as a potential metallic contaminant an item causing a disturbance of the magnetic field when the disturbance is attributable to a metallic item residing outside of the cavity.

6. An apparatus according to claim 1, wherein the signal processor separates the first signal into a resistive component and a reactive component, and the signal processor separates the second signal into a resistive component and a reactive component.

7. The apparatus of claim 6, further comprising a flux concentrator, the flux concentrator being mounted within the case so as to be adjacent to the cavity, the flux concentrator increasing inductance of the oscillator coil.

8. The apparatus of claim 8, wherein the oscillator coil is formed as first and second adjacent oscillator coils, the first and second oscillator coils being interconnected in a parallel relationship.

9. The apparatus of claim 8, wherein the oscillator coil is formed as first and second adjacent oscillator coils, the first

5   and second oscillator coils being interconnected in a series

relationship.

10.   A metal detector having a reduced metal free zone,

10   comprising:

(a) an oscillator;

(b)   an oscillator coil, the coil being electrically

15   interconnected to the oscillator so as to emit a magnetic field in

a region surrounding the oscillator coil;

(c)   a first input coil residing within the magnetic field,

the first input coil generating a first signal in response to a

20   disturbance of the magnetic field;

(d)   a second input coil residing within the magnetic field,

the second input coil generating a second signal in response to a

disturbance of the magnetic field; and

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(e)   an input coil voltage monitor, the voltage monitor being

electrically interconnected to the first and second input coils,

the voltage monitoring calculating an instantaneous ratio between

a voltage amplitude of the first signal and a voltage amplitude of

30   the second signal so as to determine a physical location of an

item causing a disturbance of the magnetic field.

35   11.   A method of detecting metal, comprising the steps of:

(a) radiating an magnetic field;

5   (b) simultaneously monitoring a voltage induced by a
disturbance of the magnetic field from a first position and a
second position; and

       (c) calculating a ratio of voltage measured at the first
position and the second position; and

10   (d) determining a location of an item causing the disturbance
of the magnetic field based on the ratio of current at each
location.

12.   The method of claim 17, further comprising the steps of:

15   (a) placing a product under test within a cavity;

       (b) determining if the item causing the disturbance to the
magnetic field is located within the cavity; and

       (c) categorizing the item as a metallic contaminant when the
item is located within the cavity.

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